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MARINE BIOFOULING AT THE NORTH BARNARD ISLANDS, QUEENSLAND.(U)
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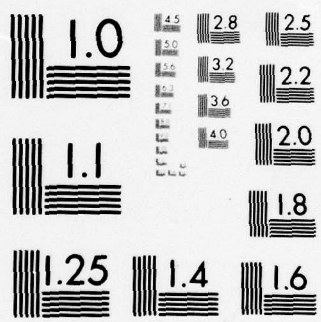

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REPORT

MRL-R-740

MARINE BIOFOULING AT THE NORTH BARNARD ISLANDS, QUEENSLAND

John A. Lewis

Approved for Public Release

FEBRUARY, 1979

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The settlement and growth of marine biofouling on non-toxic panels were studied from July 1976 - January 1978, at the JTTRE immersion facility, North Barnard Islands, Queensland. Species composition, variations in settlement abundance, community development and fouling biomass were established using panels immersed for periods which ranged from one to eighteen months. Results are considered in relation to the physical, chemical and biological parameters which control the settlement and growth of fouling species. Biomass results from this study are compared with the results of similar studies at other Australian and overseas sites.

CONTENTS

* * *

MARINE BIOFOULING AT THE NORTH BARNARD ISLANDS, QUEENSLAND

1. INTRODUCTION

Marine fouling is the assemblage of sessile and encrusting organisms which attach to and significantly affect the operating efficiency of ships, buoys, sonar equipment, seawater pipes and other marine hardware. A vast quantity of overseas research has been performed on both the composition and biological characteristics of fouling communities and on methods for their prevention (Woods Hole Oceanographic Institution, 1952; *Proc. 4th Int. Cong. Marine Corrosion Fouling* 1976). The most widely used methods of fouling control are antifouling paints which slowly leach toxins into the external medium, but even these are only effective for periods of up to 24 months (Phillip, 1974).

The Joint Tropical Trials and Research Establishment (JTTRE) provides a marine immersion facility at the North Barnard Islands near Innisfail, Queensland (Fig. 1), for the exposure of anti-fouling coatings and other materials. This facility consists of a raft from which panels can be suspended on frames. The site enables materials to be exposed under tropical conditions and the results compared with those from similar exposures in temperate waters. Baseline studies on marine fouling have been conducted at harbour, unmodified mainland, and reef sites in tropical Queensland (Garrett and Ledbury, 1974; Zann, 1975; Garrett, 1976) but these studies are not directly applicable to the raft site.

The present study was therefore implemented as JTTRE Exposure Trial No.149 with two principal objectives :

(i) to document the composition, seasons of settlement and long-term development of fouling communities on non-toxic panels immersed at the JTTRE site to enable comparison with fouling growth on experimental materials such as anti-fouling coatings, and to establish the validity of such exposure methods; and

(ii) to provide data on the composition, temporal variation and severity of fouling at the raft site as part of an MRL study to characterise fouling communities in both tropical and temperate Australian waters.

2. MATERIALS AND METHODS

2.1 Study Site

The study site is located in the North Barnard Islands (Lat. 17°40'S, Long. 146°11'E), a group of uninhabited, continental islands which lie 3 km off the mainland and approximately 25 km inshore from the Great Barrier Reef in northern Queensland (Fig. 1). The sea floor around the islands is predominantly rock and shingle with coral growths frequent on solid substrata. The JTTRE trials raft is moored approximately 200 m off the north-west shore of Kent Island (Fig. 1).

2.2 Experimental Procedure

Sandblasted panels (black unplasticised PVC, 300 × 150 × 3 mm), were suspended on frames below the raft at a depth of approximately 1 m. Four series of panels were immersed for periods which ranged from one to eighteen months. These series were as follows :

(i) one-month replacement series (July 1976 - January 1978)

(ii) three-month replacement series (July 1976 - October 1977)

(iii) July successional series (July 1976 - January 1978)

(iv) January successional series (January 1977 - January 1978)

Panels of the replacement series were immersed for successive periods of the specified duration to monitor the seasonal variation in composition and severity of fouling species settlement. Successional panels, which were all immersed at the start of the appropriate time period and removed at three-month intervals, monitored the development of the fouling community as a function of immersion time. The dates of immersion and removal of all panels are listed in Table 1.

After removal from the raft, panels were preserved in 4% aqueous formaldehyde solution and shipped to MRL in Melbourne for assessment.

Water temperature and salinity measurements from the raft site are shown in Fig. 2 (R. Pettis, in prep.).

TABLE 1

IMMERSION PERIODS OF TEST PANELS

Panel Series	Panel No.	Immersion Date	Removal Date	Immersion Period (days)
One month replacement	1	6. 7.76	6. 8.76	31
	2	6. 8.76	1. 9.76	26
	3	1. 9.76	6.10.76	36
	4	6.10.76	25.10.76	19
	5	25.10.76	9.12.76	45
	6	9.12.76	5. 1.77	27
	7	5. 1.77	2. 2.77	28
	8	2. 2.77	4. 3.77	30
	9	4. 3.77	4. 4.77	31
	10	4. 4.77	10. 5.77	36
	11	10. 5.77	16. 6.77	37
	12	16. 6.77	10. 8.77	55
	13	10. 8.77	2. 9.77	23
	14	2. 9.77	3.10.77	31
	15	3.10.77	8.11.77	36
	16	8.11.77	8.12.77	30
	17	8.12.77	6. 1.78	29
Three month replacement	1	6. 7.76	6.10.76	93
	2	6.10.76	5. 1.77	91
	3	5. 1.77	4. 4.77	89
	4	4. 4.77	10. 8.77	128
July succession	1	6. 7.76	25.10.76	112
	2	"	5. 1.77	184
	3	"	4. 4.77	273
	4	"	10. 8.77	401
	5	"	3.10.77	455
	6	"	6. 1.78	550
January succession	1	5. 1.77	4. 4.77	89
	2	"	10. 8.77	217
	3	"	3.10.77	271
	4	"	6. 1.78	366

2.3 Assessment Procedure

The following procedure was adopted for the assessment of panels :

(i) Species composition - all organisms present on the panels were identified, to species level where possible, and recorded.

(ii) Species density - every individual of each species present within two 13 cm × 3 cm transects, 7 cm from the top and bottom edges of the panel, were counted using a binocular dissecting microscope (magnification range ×6 to ×40). Counts were recorded as individuals per 0.01 m^2.

Organisms with growth habits not conducive to direct counts, such as stoloniferous hydroids, were assessed on a 0-10 scale of abundance. Forty prelocated fields (×30 magnification) on each panel were examined for the presence of these species and results divided by four to give a nearest whole-number rating.

(iii) Species cover - the number of intercepts of each species with a 0.5 cm grid were counted over the central 24 cm × 13 cm area of the panel and converted to a percentage. Total panel cover was estimated by the summation of cover values for individual species.

(iv) Biomass - measurements of the wet and dry (panel oven-dried to constant weight) weight of fouling on successional panels were made by comparison with the pre-immersion panel weights. The dry weights of fouling on replacement panels were measured by weighing the growth scraped from a 100 cm^2 area in the centre of each panel side.

All parameters, with the exception of biomass, were assessed separately for the two faces of the panels. The outward face from the raft frame was designated front but this does not necessarily represent a constant directional aspect.

3. RESULTS

3.1 Composition of the Fouling Community

A systematic list of species recorded on the test panels, together with a comparative rating of their frequency of occurrence on the different panel series, is presented in Table 2. Where possible, entities have been identified to species level. However, specific identity was not always possible due either to insufficient material, the presence of only juvenile stages, or inadequacies in the relevant taxonomic literature. In such cases, organisms are listed at the level to which they could confidently be determined. No attempt was made to determine either diatom or foramniferan species. Errant taxa are included in the species list but will not be considered further in this report.

The dominant components of the fouling community on panels from the North Barnard Islands were algae (diatoms, Cladophora sp., *Feldmania indica, Laurencia obtusa, Heteroderma* sp.) and bryozoa (*Aetea truncata, Membranipora sarvati, Rhamphostomella* sp., *Savignyella lafonti, Thalamoporella gothica).* In addition to these groups, one species of hydroid (*Campanularia delicatula*) and a bivalve mollusc (*Crassostrea* sp.) were frequently dominant in the community. A total of 49 algal, 40 sedentary invertebrate and 26 errant invertebrate taxa were recorded during the study period.

TABLE 2

SYSTEMATIC LIST OF TAXA COLLECTED ON TEST PANELS TOGETHER WITH THEIR FREQUENCY OF OCCURRENCE

Panel series: (i) one month replacement; (ii) three month replacement; (iii) successful.

Frequency of occurrence: + rare; ++ uncommon; +++ common; ++++ very common.

	Panel Series (i)	(ii)	(iii)
I. ALGAE			
Phylum: Chrysophyta			
Diatom spp.	++++	++++	++++
Phylum: Cyanophyta			
Oscillatoria sp.	+	+	++
Spirulina sp.		+	
Phylum: Chlorophyta			
Bryopsis sp.			+
Caulerpa brachypus Harvey			+
Chaetomorpha sp.		+	+
Cladophora sp.	++++	+++	+++
Cladophoropsis (?) sp.			+
Derbesia sp.			+
Enteromorpha clathrata (Roth) Greville	++++	++	++
Valonia ventricosa J. Agardh		+	+
Phylum: Phaeophyta			
Colpomenia sinuosa (Roth) Derbes & Solander	++		
Dictyota dichotoma (Hudson) Lamouroux		++	++

Phylum: Phaeophyta (Cont.)	Panel Series		
	(i)	(ii)	(iii)
Dictyota sp.	+++	++	++++
Feldmannia indica (Sonder) Womersley & Bailey	++++	++++	+++
Padina australis Hauck	+		++
Pockockiella variegata (Lamouroux) Papenfuss		++	+++
Sphacelaria furcigera Kuetzing	+	+++	+++
Phylum: Rhodophyta			
Acanthophora spicifera (Vahl) Boergesen	+	++	++
Amansia glomerata C. Agardh			+++
Antithamnion antillanum Boergesen		+	+
Antithamnionella sp.	++	+	++
Callithamnion sp.	+		
Ceramium flaccidum (Kuetzing) Ardissone	++	+	+
Ceramium sp. 1	++	+	+
Ceramium sp. 2	++	+	++
Champia sp.	+	+	+
Chondria sp. 1			
Chondria sp. 2		+	++
Dasya sp.	++	++	+++
Galaxaura sp.		++	++
Gelidiopsis scoparia (Montagne & Millardet) Schmitz			
Griffithsia sp.			++
Herposiphonia tenella (C.Agardh) Ambronn	++	+++	+++
Heteroderma sp. together with *Lithoporella melobesioides* (Foslie) Foslie	++++	++++	++++
Heterosiphonia wurdemanni var *laxa* Boergesen	+		++
Hypnea sp. 1	+	+	++
Hypnea sp. 2			+
Hypoglossum sp.	+		+
Jania sp.	+	+++	++++
Laurencia obtusa (Hudson) Lamouroux	++++	+++	++++
Laurencia sp. 1			+
Laurencia sp. 2			+
Lejolisea sp.			+
Oligocladus sp.	++		
Peyssonellia sp.	+	+	+++

	Panel Series		
	(i)	(ii)	(iii)
Phylum: Rhodophyta (Cont.)			
Polysiphonia scopularum Harvey	+++	+++	++++
Polysiphonia sp.	++	++	+++
Spyridia filamentosa (Wulfen) Harvey	+		+
Tolypiocladia glomerulata (C.Agardh) Schmitz	+	+	++
II. SEDENTARY INVERTEBRATES			
Phylum: Porifera			
Class: Calcarea			
Sycon sp.	++	+++	+++
Class: Demospongiae			
Suberites (?) sp.	+++	++	+++
Phylum: Coelenterata			
Class: Hydrozoa			
Campanularia delicatula (Thornley)	++++	++++	++++
Halecium sp.	+		
Halopteris diaphana (Heller)		+	
Lytocarpus philippinus (Kirchenpauer)		+	+
Obelia longicyatha Allman	++	+	
Obelia nodosa Bale	++	+	
Staurocoryne sp.	+		
Thecocarpus phyteuma (Kirchenpauer)	+++	+	+++
Class: Anthozoa			
Coral sp.	+	+	+
Anemone sp.	+		
Phylum: Annelida			
Class: Polychaeta			
Hydroides brachyacantha Rioja		++	+++
Hydroides monoceros Gravier			+
Salmocina dysteri Huxley	+++	+	++++
Spirobranchus tricornis (Moerch)			+
Spirorbis sp.	++	+	+

	Panel Series		
	(i)	(ii)	(iii)
Phylum: Mollusca			
Class: Gastropoda			
Vermatid sp. 1	++		+++
Vermatid sp. 2		+	+
Class: Bibalvia			
Cleidothaerus sp.			+
Crassostrea sp.	+++	+++	++++
Lanistina sp.	+		++
Modiolus sp.		+	+
Pinctada fucata (Gould)	+	+	+++
Phylum: Arthropoda			
Class: Crustacea			
Subclass: Cirripedia			
Balanus amphitrite Darwin	++	++	++++
Tetraclita sp.	+	++	++++
Phylum: Bryozoa			
Class: Gymnolaemata			
Aetea truncata (Landsborough)	++++	++++	++++
Caulibugula dendrograpta (Waters)		+	+
Electra bellula var. *bicornis* (Hincks)			+
Lichenopora sp.			+
Membranipora sarvati (Audouin)	++++	+++	++++
Microporella orientalis (Harmer)		+	+
Parasmittina sp.	+++	+++	+++
Rhamphostomella sp.	++++	++++	++++
Savignyella lafonti (Audouin)	+++	++++	++++
Scrupocellaria scabra (van Beneden)	+	+	+
Thalamoporella gothica (Busk)	++++	++++	++++
Vitacellidae sp.	+		
Phylum: Chordata			
Class: Ascidiacea			
Pyura sp.	+	++	++
Trididemnum sp.	++		++
Compound ascidian sp.	+		

	Panel Series (i)	(ii)	(iii)
III. ERRANT INVERTEBRATES			
Phylum: Protozoa			
Superclass: Sarcodina			
Class: Rhizopodea			
Foramnifera spp.	++++	++	+++
Phylum: Platyhelminthes			
Class: Turbellaria			
Turbellaria sp.			+
Phylum: Nematoda			
Nematode sp.			+
Phylum: Annelida			
Class: Polychaeta			
Autolytus sp.	+		+
Dorvillea sp.			+
Eunice antennata (Savigny)			+
Eunice sp.		+	+
Lysidice ninetta Audouin & Milne Edwards			+
Nereidae sp.	+		
Nereis sp.	+		
Phyllodoce sp.	+		
Platynereis isolita Gravier	++		
Scalisetosus fragilis (Claparede)	+		+
Syllis prolifera Krohn	+	+	+++
Syllis variegata Grube	++		++
Syllis sp. 1			++
Syllis sp. 2			+
Phylum: Mollusca			
Class: Gastropoda			
Australomitre sp.			+
Gastropod sp. 1	+		+
Gastropod sp. 2		+	

	Panel Series		
	(i)	(ii)	(iii)
Phylum: Arthropoda			
Class: Pycnogonida			
Pycnogonid sp.	+		
Class: Crustacea			
Subclass: Copepoda			
Copepod spp.	++		+
Subclass: Cirripedia			
Cypris larvae	+++		+
Subclass: Malacostraca			
Tanadaisid spp.	+	+	++
Subclass: Isopoda			
Isopod spp.	++	++	+
Subclass: Amphipoda			
Caprellid spp.	++		
Gammarid spp.	+++	+	++++

The epibiotic community on one month panels consisted of a low 'turf', formed by diatoms, filamentous algae, stoloniferous hydroids and the stoloniferous bryozoa *Aetea truncata*, which covered most of the panel surfaces (Plate 1). Potential macrofouling species, such as thalloid algae, encrusting bryozoa, bivalves and barnacles, were present as individual juveniles but did not contribute to the overall panel cover or biomass at this stage of community development. These larger species, however, dominated the biomass and substratum cover on panels immersed for periods longer than one month (Plates 2-4).

The number of algal species which settled on one-month replacement panels increased through the study period (Fig. 3a). The intermediate peaks in species number were due to longer immersion of the respective panels (Table 1). The number of sedentary invertebrate species increased to a peak in March 1977, nine months after the commencement of the study (Fig. 3b). Numbers dropped over the winter period but subsequently increased to pre-winter diversity in early summer of 1977-78.

Variations occurred in the number of algal species on three-month replacement panels through the study period whereas the number of invertebrates remained constant (Fig. 4a). Species numbers of algae and invertebrates on the successional series, with the exception of algae on the January series, increased over the first three months of immersion and then stabilised (Figs 4b, c). Algal species on the January series increased in number throughout the twelve-month study period (Fig. 4b).

3.2 Variation in Settlement of Species on One-Month Panels

The abundance of settlement by the dominant species on panels of the one-month replacement series are illustrated in Figures 5-7. For each species, with the exception of diatoms, a season of peak settlement can be defined as follows :

late winter/early spring	*Feldmannia indica*
	Enteromorpha clathrata
	Laurencia obtusa
	Heteroderma sp.
	Thecocarpus phyteuma
late spring/early summer	*Aetea truncata*
	Rhamphostomella sp.
	Thalamoporella gothica
	Salmocina dysteri
	Sycon sp.
	Obelia spp.
	Campanularia delicatula
late summer/early autumn	*Parasmittina* sp.
	Balanus amphitrite

Cladophora sp. settled from late spring through to early autumn with a temporary abatement in mid-summer and *Crassostrea* sp. settled, in low numbers, discontinuously from spring through to autumn.

The settlement of algal and invertebrate macrofouling species were negligible during the initial four months of the study period (Figs 6, 7). The peak settlement periods of some species, for example *Thalamoporella gothica* and *Salmocina dysteri* (Fig. 7), also varied between successive years.

Invertebrate species were generally distributed in similar densities on both faces of the one-month panels (Fig. 7). Algal species however, tended to settle more abundantly on one face and this was particularly apparent for *Enteromorpha clathrata* and *Heteroderma* sp. (Fig. 6). Settlements by these species were confined to the back face of panels for all but the last three months of the study period when settlement shifted to the front.

Biomass of fouling on the one-month panels was highest in the first month of the study (Fig. 8). Subsequent peaks occurred in mid-summer and late winter.

3.3 Variations in the Settlement of Species on Three-Month Panels

The composition of fouling communities on three-month replacement panels is illustrated in Figure 9. 'Turf' species dominated in July-October 1976 and April-August 1977 whilst an encrusting bryozoan species

dominated on each of the panels immersed in the intervening period. These bryozoan species were *Thalamoporella gothica* from October 1976 - January 1977 and *Membranipora sarvati* from January-April 1977. Macrophytic algal species, predominantly encrusting corallines, were confined to the back face of panels.

The biomass of fouling varied with the composition of the settled species (Fig. 9a). Highest biomass was attributed to *Membranipora* growth on the front of the January-April 1977 panel.

3.4 Pattern in the Development of the Fouling Community on Successional Panels

The biomass of fouling growth on the successional panel series showed a near linear increase with immersion time (Fig. 10). Biomass on the July series was higher than that on the January series, due largely to differences in the community composition on each series (see below).

Fouling growth covered panels within 3 months of immersion (Fig. 11, Plates 3a, 4a) with the maximum cover values of 150% of panel area being attained after 6 months. Maximum values of greater than 100% were confined to one panel face and due to the presence of a macrophytic algal canopy over species with a more prostrate habit (Plate 3b). Such algae were subsequently displaced from the community and panel-cover then varied between 100 and 130% (Fig. 11).

Initial panel cover on the July series panels was by a turf of diatoms, filamentous algae and stoloniferous hydroids and bryozoa (Figs 12, 13). This association was subsequently overgrown by the encrusting bryozoan *Thalamoporella gothica* after six months which was, in turn, overgrown by an encrusting sponge (Fig. 12). The molluscs *Crassostrea* sp., *Pinctada fucata* and the barnacle *Tetraclita* sp. were present on panels through most of the immersion period but did not contribute significant cover to the community until after fourteen months immersion (Fig. 12). A canopy of macrophytic algae, which developed on the front of panels after six months immersion, declined in abundance to almost complete absence after eighteen months. Dominant macrophytes in the canopy were *Laurencia obtusa, Padina australis* and *Dictyota* sp.

Community development on the January series passed through only two distinct phases on the front of panels and turf persisted throughout the immersion period on the reverse side (Fig. 14). The turf components were not constant over this period however, as the initial colonists, *Feldmannia indica, Campanularia delicatula* and *Aetea truncata*, declined in abundance after six months (Fig. 15) to be replaced by the hydroid *Obelia nodosa*, the bryozoan *Savignyella lafonti* and a diverse assemblage of filamentous algae which included *Polysiphonia scopularum, Herposiphonia tenella, Ceramium* spp. and *Lejolisia* sp. The most abundant encrusting bryozoa, which settled on the front of panels after nine months (Fig. 14), were *Membranipora sarvati* and *Parasmittina* sp. whilst algal cover on the back of panels was predominantly due to the encrusting coralline *Heteroderma* sp. The polychaete *Salmacina dysteri* was frequent after twelve months immersion (Fig. 14).

4. DISCUSSION

4.1 Variations in the Composition and Abundance of Settlement

The composition and abundance of fouling species on panels immersed for successive one-month periods at the North Barnard Islands varied throughout the year (Figs 5-7). Each species, with the exception of diatoms (see below), had a period of peak settlement (Section 3.2) and generally did not settle continuously through the study period. The majority of invertebrate species showed maximum settlement from late spring through until early summer (Figs 5,7) whilst macrophytic algae were more abundant in the period from late winter to early spring (Figs 5,6).

Environmental conditions, which control reproductive and settlement processes, determine the time of settlement by particular species. Settlement may be stimulated by one or a combination of factors which include water temperature, salinity, light quality, water quality and food supply (Perkins, 1974; Woods Hole Oceanographic Inst., 1952). At the North Barnard Islands, the settlement of many species coincided with the onset of warmer temperatures (Fig. 2) which may indicate an optimum temperature at which reproductive activity is triggered. *Balanus amphitrite*, a common species in harbour and estuarine environments (OECD, 1963) settled during late summer and early autumn (Fig. 7) when salinities were reduced (Fig. 2). Salinity may, therefore, be the parameter which controls settlement of this one species. Culture studies, in which the environment can be controlled and manipulated, are necessary to determine those parameters which influence the life-cycle of each species.

The continuous settlement of diatoms (Fig. 5) may represent either a wide tolerance of these species to environmental conditions or the cumulative effects of settlement peaks by different species. Detailed identification and numeration of diatoms on each panel at the species level would elucidate the trends in colonisation.

The prime factor which determines the abundance of fouling settlement is the concentration of invertebrate spat or algal spores in the water column. Although spore or larval release is dependent on favourable environmental conditions, the absolute concentration of juvenile stages in an area of water is dependent on either the presence of reproductive adults in the immediate region, or on the ability of planktonic stages to migrate into the area as a result of their longevity.

The commencement of this fouling study coincided with the initial immersion of the trials raft and, due to the isolation of the raft from established fouling communities, the growth of fouling on the raft structure could be expected to have influenced the settlement of species on short-term test panels. The establishment of a single individual of any species on the raft by chance would, if the individual reached reproductive maturity, lead to the release of vast numbers of progeny into the waters immediately adjacent to the test panels. The probability of settlement of a species on the panels would therefore be increased many-fold.

The absence of macrofouling species from one-month panels during the initial four months of the study (Figs 6,7) and the increase in the number of species present as the study progressed (Fig. 3) suggests a strong influence from raft-fouling on the species composition on panels. The more rapid colonisation of the January series of successional panels than the July series (Fig. 4) can be attributed to the establishment of a fouling community on the raft during its initial six months immersion so that direct recruitment to the panel surfaces could occur. Schoener (1974) discussed seasonal changes in the colonisation of panels and suggested that, in seasonally-varying environments, the rapidity with which colonisation proceeds is also variable. Therefore, the more rapid colonisation of January panels may be partly due to their immersion in mid-summer and not be completely a function of raft-fouling.

The influence of the local fouling community can effectively mask the natural seasonal variations in fouling settlement. Although some recurrent trends were present in the settlement of individual species during the study period, which enabled the determination of peak settlement periods (Section 3.2), the abundance of settlement differed considerably between settlement seasons in successive years (Figs 6,7). Seasonal periodicity in the composition and abundance of settlement on one-month panels would depend on the stability of surrounding populations. At the North Barnard test site, stability is unlikely to occur before a climax fouling community is established on the raft. The time required for the development of a climax community at this site is discussed below (Section 4.2).

The effects of raft-fouling discussed above do not generally apply to primary colonising species which form the initial turf cover on panels. The planktonic larval or spore stages of these species are generally abundant enough in inshore waters to rapidly colonise newly-available substrata. Short life-cycles and fast growth rates enable the establishment of populations within one month of the immersion of a substratum. Primary colonising species in the present study included diatoms, *Feldmannia indica*, *Campanularia delicatula* and *Aetea truncata*.

An extreme case of colonisation from the close proximity of source populations occurred on a three-month replacement panel which was immersed from January to April. The front of this panel was dominated by a single colony of the bryozoan *Membranipora sarvati* (Fig. 9, Plate 2) which spread on to the panel from either the bolt that held the panel in place or the frame which supported the base of the panel. The growth pattern of bryozoa which settled directly on the panel was a multitude of discrete colonies (Plate 1). The *Membranipora* growth markedly reduced the diversity of algal species on the panel (Fig. 4).

The diversity of species on one-month panels also depended on the actual period of immersion. Panels immersed for longer periods supported a higher number of algal species (c.f. Table 1 and Fig. 3) than panels with a shorter immersion period. This phenomenon was less apparent for invertebrate species and may reflect the smaller size of algal individuals at the time of settlement and the growth period required before the germlings can be detected. Colonisation curves for algal species on successional panels (Fig. 4) suggest that primary colonisers are recognisable within three months of settlement, whereas invertebrate species numbers stabilise within one month.

Growth by any particular algal species is governed by the optimum light intensity for photosynthesis and this leads to a bias, by most species, toward one face of the panel (Fig. 6). The optimum range varies between species and different floras therefore develop under different light regimes as, for example, on the front and reverse of a vertical, north-south oriented panel. The reversed preference by algae for the front and back of one-month panels in October 1977 (Fig. 6) implies a reversal in the direction of incident light. A change in the orientation of either the raft or the panel frames could have caused this reversal.

4.2 Development of the Fouling Community

Initial panel colonisation was by a turf-like community of opportunistic species which covered the entire surface of panels within one month of immersion (Fig. 11). Once the substratum was covered, biotic parameters, which acted within the established community, replaced settlement as the principal controls on the structure of the fouling community. Large, slow-growing species settled on, or between, the primary colonisers and then gradually displaced or overgrew them (Figs 12, 14; Plates 3, 4). The rate of this process depended on the composition of species and therefore the time of immersion of the panels. Primary colonisers were replaced as community dominants within three months (Figs. 12, 13) on panels immersed prior to the peak period of invertebrate settlement (Figs 6, 7) but persisted for up to six months on panels immersed subsequently (Figs 14, 15).

A generalised sequence of development for the fouling community observed on successional panels would be as follows :

(i) primary turf - diatoms, *Feldmannia indica*, *Campanularia delicatula* sp., *Aetea truncata*

(ii) secondary turf - (when primary turf is not overgrown within six months) - filamentous algae, hydroids, *Savignyella lafonti*

(iii) encrusting bryozoa

(iv) encrusting sponge

(v) heterogenous community - bivalve molluscs, barnacles, serpulids, plus elements of stages (i) - (iv).

Stages (iii) and (iv) gained dominance by overgrowing the preceding stages. Stage (v), the heterogenous community, was a consequence of three interrelated processes :

(i) the growth of molluscs and barnacles which, although present throughout the study, only reached a size capable of displacing encrusting species after fourteen months,

(ii) the sloughing of established growth due to the death of encrusting species which had been overgrown, and

(iii) the recolonisation of primary substrata, created by sloughing, and secondary substrata, the shells of barnacles and molluscs, by opportunistic species.

The growth of macrofouling algae was largely independent of the above sequence as the dominant species formed a canopy over the encrusting growth (Plate 3) and only occupied an area of primary substratum equivalent to the size of their holdfasts. As individuals died, however, they were not replaced as new plants were unable to establish on the closely populated panels. The area of algal cover therefore declined to near extinction after 18 months immersion (Fig. 12) but could be expected to increase as sloughed areas are recolonised. Algal distribution was again biased toward one face of the panels, presumably due to the effects of light intensity.

The development of a coral reef was studied on block moles in the Red Sea (Schuhmacher, 1977) and four phases were identified: start (0-4 months), preparation 4-12 months), pioneer framebuilding (1-6 years) and framework binding (6-12 years). Up until the phase of pioneer framebuilding by coral colonies, species were essentially those of a fouling community and included rock-attached bivalves, barnacles, filamentous algae and calcareous algae. The similarity of this community to that on successional panels in the present study suggests that the eventual climax community would be dominated by coral colonies. Sutherland and Karlson (1977) conclude, however, that a stable climax is never achieved in a fouling community on panels. Dramatic changes in community structure were produced each year by the combined addition of species through larval recruitment and subtraction of species as a result of adult mortality. Schoener (1974) found few fouling communities in which an equilibrium number of species was approached during panel studies.

With the exception of algae on the January series (Fig. 4), the number of species on successional panels at the North Barnard Islands approached equilibrium within four months of immersion. The composition of the community after eighteen months immersion was, however, still unstable (Fig. 12) and no potentially long-lived species such as corals were present. The likely outcome of community development on the panels is postulated to be a heterogenous community of species in which no one species obviously dominates over an extended period of time. Instead, an oscillation between dominant species would occur which depended on the settlement time and abundance of organisms, mortality of established biota through natural mortality, predation or sloughing and the competitive interactions between species. Test panels present too small an area of substratum to adequately represent the broad complexities associated with a climax coral reef community in which fouling species only occupy small cryptic habitats.

4.3 Biomass

The biomass of fouling on one-month replacement panels was dependent on the composition and abundance, though not on the diversity, of the fouling species. Considerable silt and organic debris, attached to panels during the first two months of the study and presumably bonded by bacterial slime, formed the highest mass recorded on panels during the eighteen-month study period (Fig. 8). The abundance of organic debris did not recur in 1977 and may have been a phenomenon related to the immersion time of the raft. Formation of primary film is the initial phase of substrate colonisation (Wood, 1967) and, in tropical waters, secondary fouling species subsequently appear after two weeks (Zann, 1975). The low abundance of secondary fouling species at the North Barnard site during the initial months of the study (see Section 4.1) would enable the primary film to persist for a longer duration and more debris to accumulate.

Subsequent biomass peaks were due to the presence of a single dominant species which exhibited rapid colonisation and fast growth. Dense growth of *Feldmannia indica* in early spring of successive years caused increased biomass at these times whilst the biomass peak in early summer 1977 was due to extensive growth of the hydroid *Obelia nodosa* (Figs 5, 8; Plate 1). Any predictive statements on seasonal variation in fouling biomass would depend on the assumption that these species would recur periodically in similar abundances.

The biomass of fouling on the January series of successional panels was considerably lower than that on the July series in all but the first three months of the study (Fig. 11). Initial differences were due to the more rapid colonisation of the January series (see Section 4.1) whilst later variation was directly attributable to the fouling composition. The molluscs *Crassostrea* sp., *Pinctada fucata* and the barnacle *Tetraclita* sp., did not settle on January panels as these were immersed after the settlement period of the species. Growth of these species on the July series accounted for most of the biomass.

The dry weight of fouling per unit area at the North Barnard Islands after six and twelve months is lower than that at a variety of Australian and world sites (Table 3). Comparable figures were only recorded at nearby sites (Zann, 1975) and in the temperate waters of Nova Scotia in the western Atlantic (De Palma, 1969). The low weights are primarily due to the low numbers of 'hard' fouling species in Queensland waters and their low density on panels at the North Barnard site. Predominant growths were of encrusting or turf-like habit which provide rapid substratum cover but with a low thickness and, therefore, biomass per unit area.

TABLE 3

COMPARISON OF THE BIOMASS OF FOULING AT THE NORTH BARNARD ISLANDS WITH OTHER TROPICAL AND TEMPERATE SITES

Site	Dry Wt. of Fouling/unit area (g/cm^2)		Source
	6 months	12 months	
Nth Barnard Islands, Qld (Trop.)	0.02-0.04	0.03-0.08	
Magnetic Island, Qld (Trop.)	0.01	0.04	Zann, 1975
Lodestone Reef, Qld (Trop.)	0.02		Zann, 1975
Clump Point, Qld (Trop.)	0.07		Zann, 1975
Sydney, N.S.W. (Temp.)	0.47	0.83	Russ, 1977
Melbourne, Vic. (Temp.)	0.17-0.44	0.11	Russ, 1977; Dunstan, 1978
Cockburn Sound, W.A. (Temp.)	0.05-0.24	0.22	Dunstan (1978)
Thailand (Trop.)	0.01-0.67	0.27-0.67	De Palma, 1970, 1977
Japan (Sub-trop.)	0.94	1.12	De Palma, 1968
Japan (Temp.)	0.63-0.66	0.58-0.64	De Palma, 1968
Washington, U.S.A. (Temp.)	0.04-0.18	0.24-0.30	De Palma, 1976
Nova Scotia, Can. (Temp.)	0.01	0.02	De Palma, 1969

5. CONCLUSIONS

1. A total of 49 algal, 40 sedentary invertebrate and 26 errant invertebrate taxa were recorded on test panels from the North Barnard Islands. Dominant components were algae and bryozoa.

2. Each species, with the exception of diatoms, showed a defined season of settlement on panels immersed for one month. Invertebrate species generally settled in similar densities on both faces of panels whilst algae were biased in distribution toward one face.

3. The composition of fouling on the raft structure influenced the settlement composition and abundance of species on test panels.

4. A fouling community completely covered panels within three months of immersion then developed as a succession of stages dominated by different species. These species displaced or overgrew preceding dominants.

5. The likely outcome of community development is postulated to be a heterogenous community of species in which no one species dominates over an extended period of time. Variable settlement time and abundance, removal of established biota through natural mortality, predation or sloughing and the competitive interactions between species would each act to prevent the occurrence of a stable climax.

6. Biomass of fouling depended on the time and duration of immersion. Dry weight of fouling per unit area is generally lower than at other Australian and overseas sites due to the low numbers of 'hard foulers'.

6. ACKNOWLEDGEMENTS

I wish to thank the staff of the Joint Tropical Trials and Research Establishment, and in particular Mr. J. Hill and Ms. T. Porrill, for their organisation of the immersion, withdrawal and shipment of test panels to MRL. I also wish to acknowledge Ms. Roberta Townsend of the University of Melbourne for identification of encrusting coralline algae and Mr. I. Dunstan of MRL for assistance in the identification of many invertebrate species.

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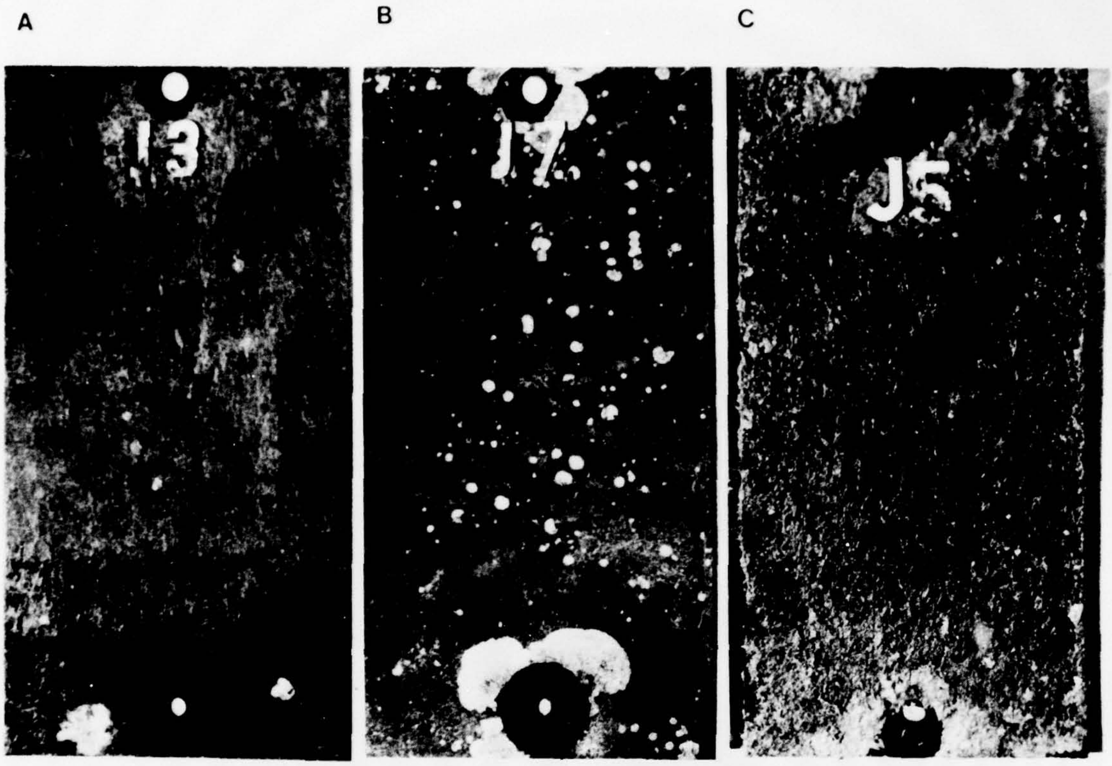

PLATE 1 - Variation in dominant species on one-month replacement panels immersed during different periods of the study.

a) *Feldmannia indica* (1.9.76 - 6.10.76).
b) encrusting bryozoa, *Campanularia delicatula* (5.1.77 - 2.2.77).
c) *Obelia nodosa* (8.11.77 - 8.12.77).

A B

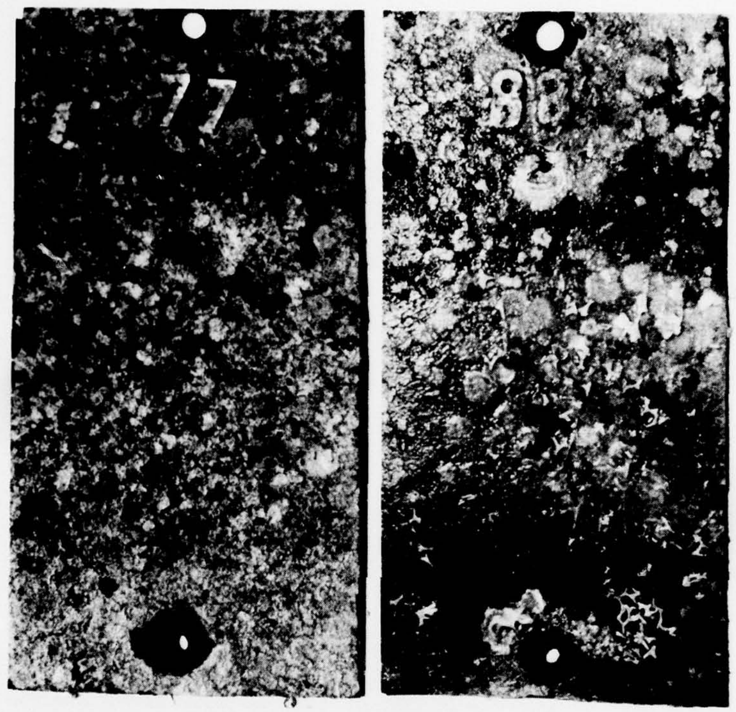

PLATE 2 - Three-month replacement panels showing the different growth forms of bryozoa settling directly on the substratum (a, *Thalamoporella gothica*) and spreading from the bolts holding the panels in place (b, *Membranipora sarvati*).

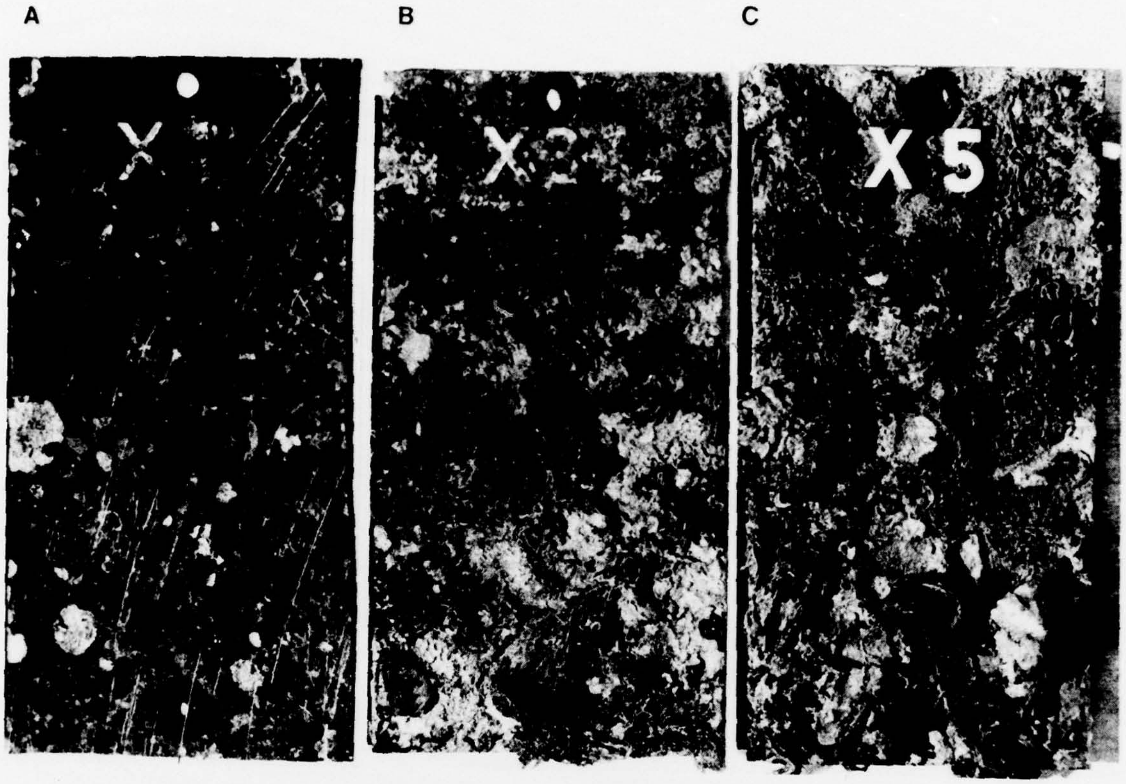

PLATE 3 - Stages in the development of the fouling community on the July successional panel series.

a) primary turf (112 days immersion).
b) encrusting bryozoa, higher algae (273 days).
c) heterogenous community (455 days).

A B

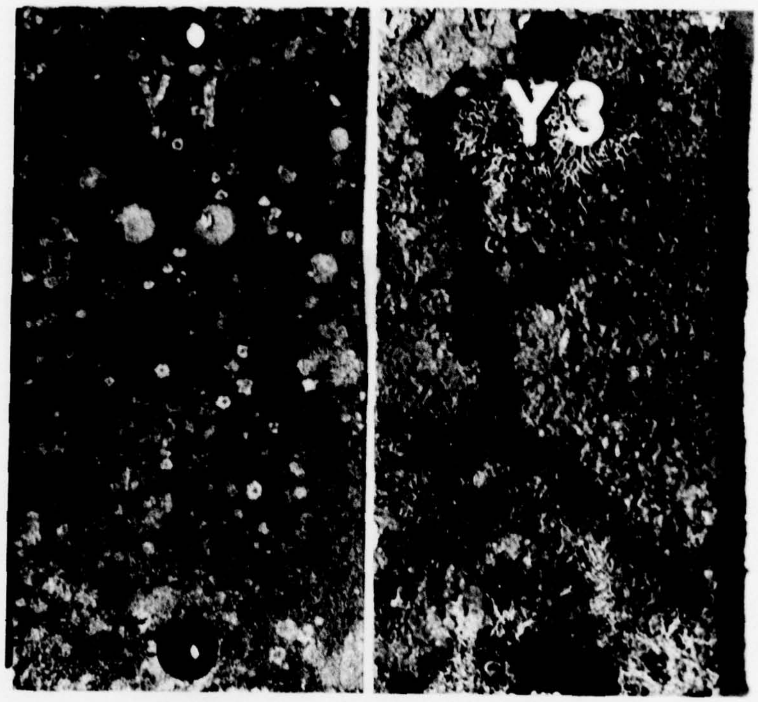

PLATE 4 - Stages in the development of the fouling community on the January successional panel series.

a) primary turf (89 days)
b) encrusting bryozoa (271 days).

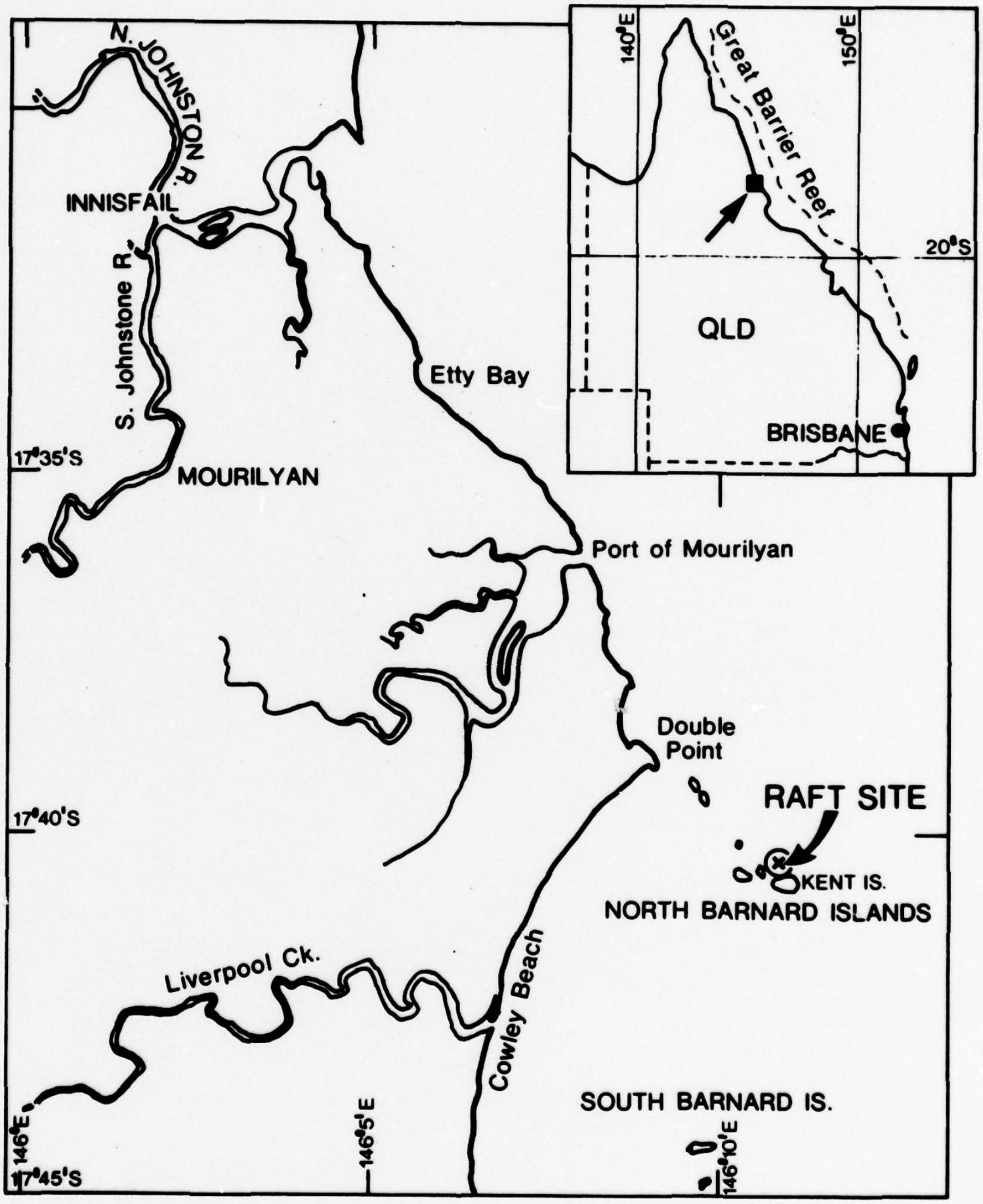

FIG. 1 - Site of the JTTRE marine immersion facility at the North Barnard Islands, Queensland.

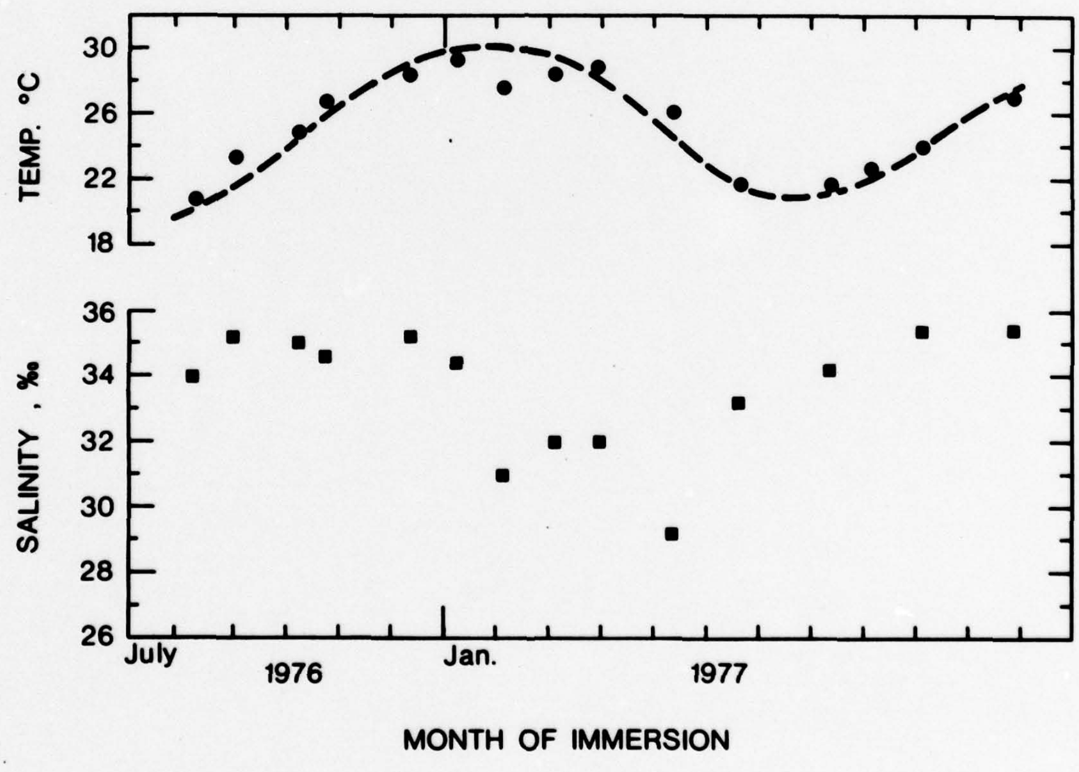

FIG. 2 - Variation in water temperature and salinity at the raft site over the study period.

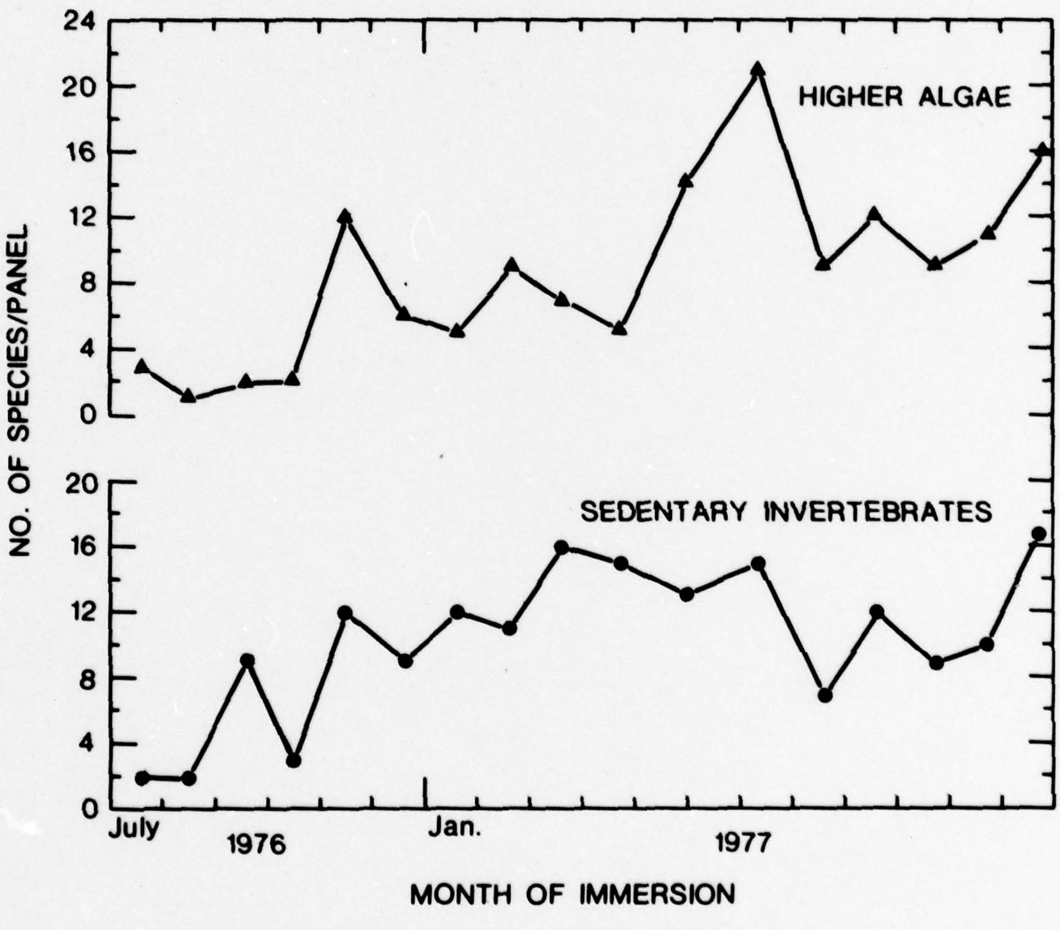

FIG. 3 - Number of species detected on one-month replacement panels for each month of the study period.

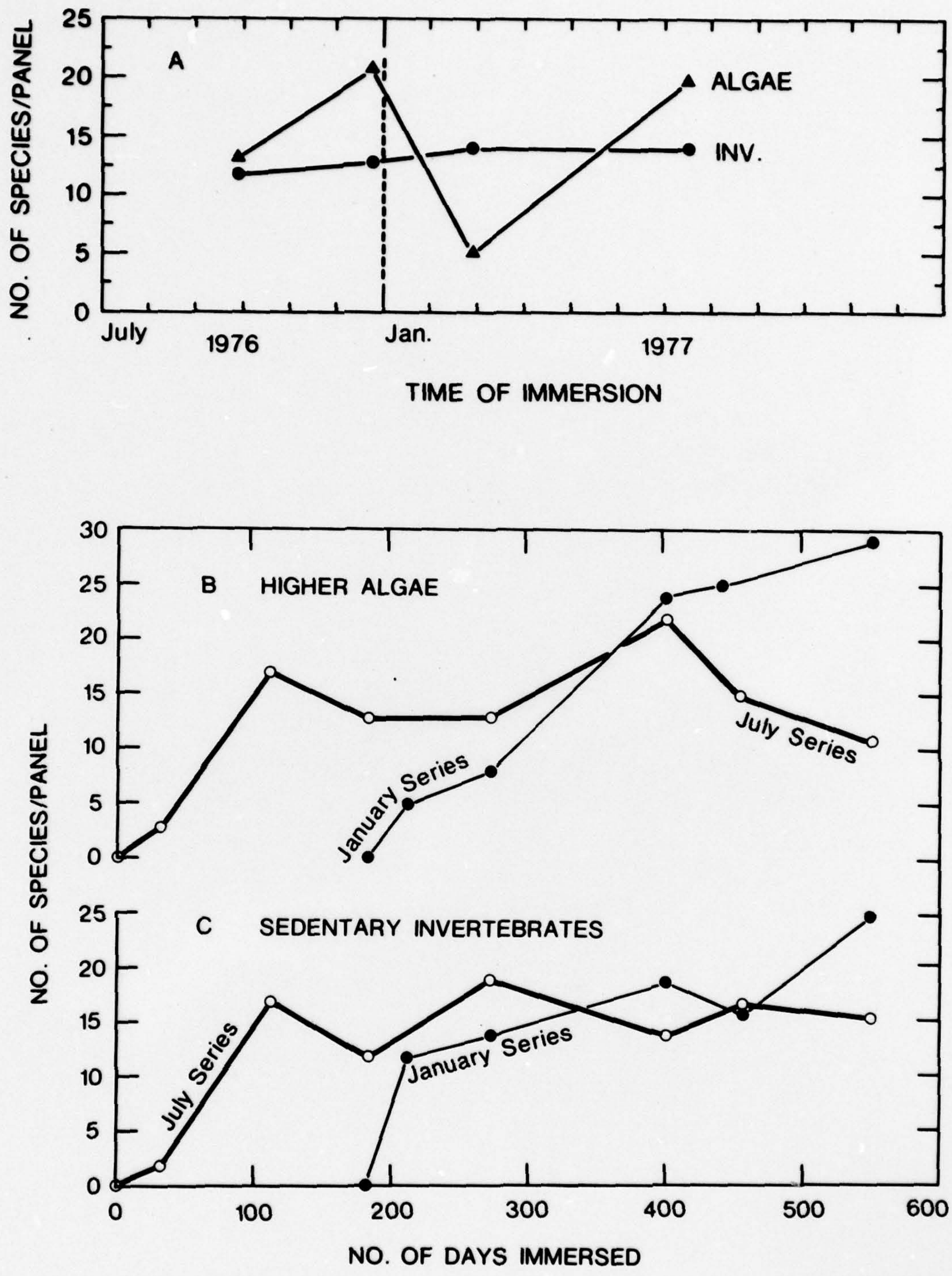

FIG. 4 - Number of species detected on three-month replacement and successional series through the study period.

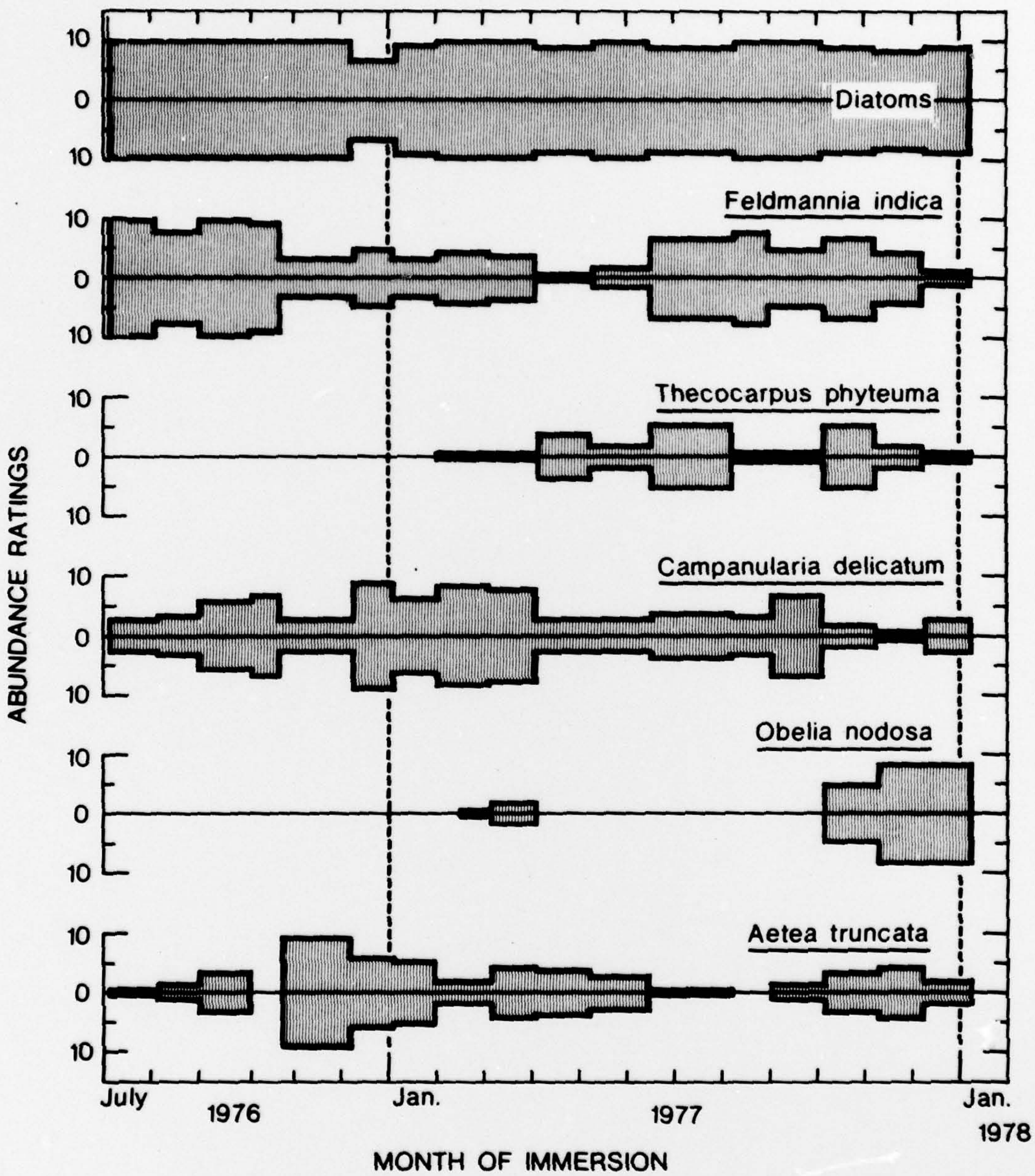

FIG. 5 - Variation in abundance of primary turf components on one-month replacement panels.

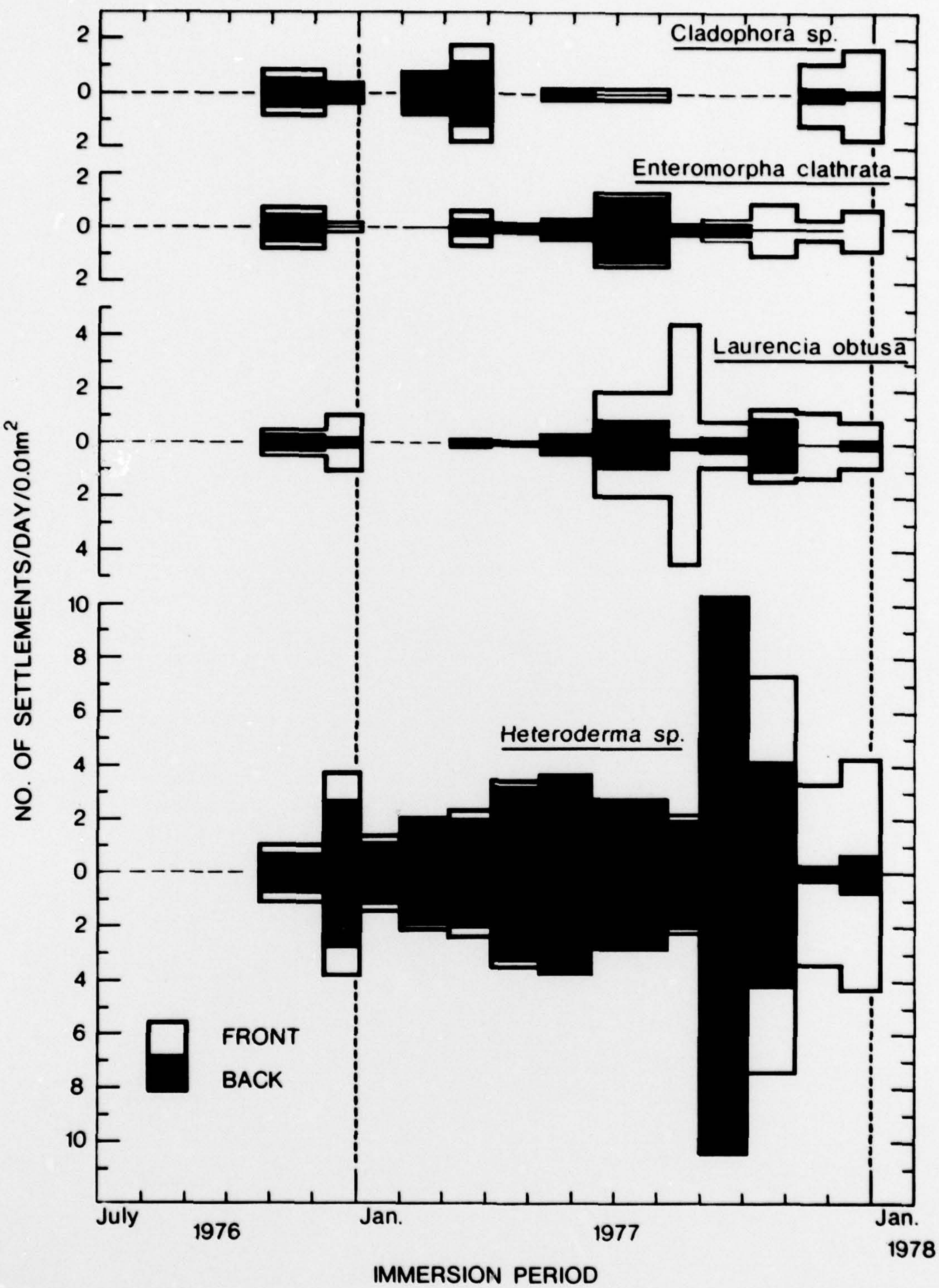

FIG. 6 - Variation in abundance of higher algae on each face of the one-month replacement panels through the study period.

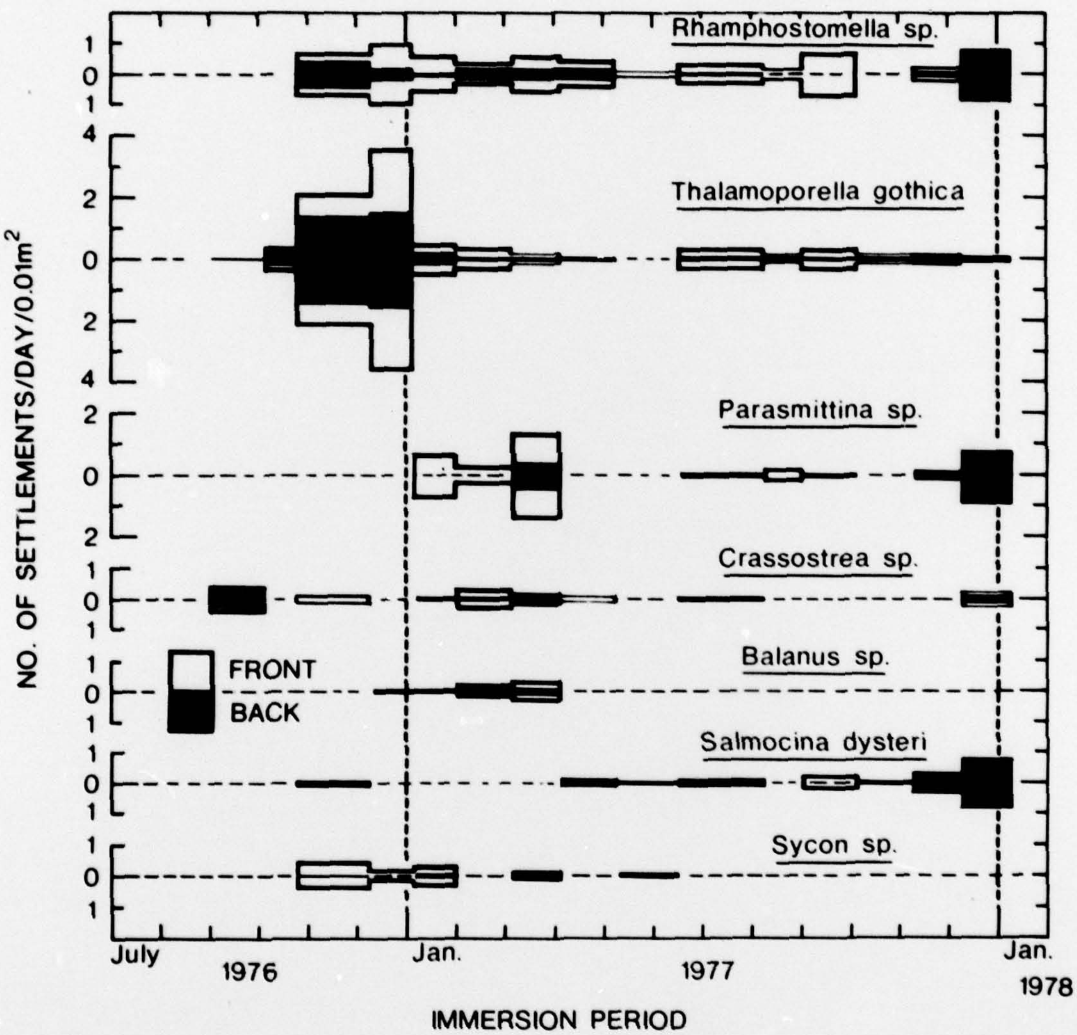

FIG. 7 - Variation in abundance of macrofouling invertebrates on each face of the one-month replacement panels through the study period.

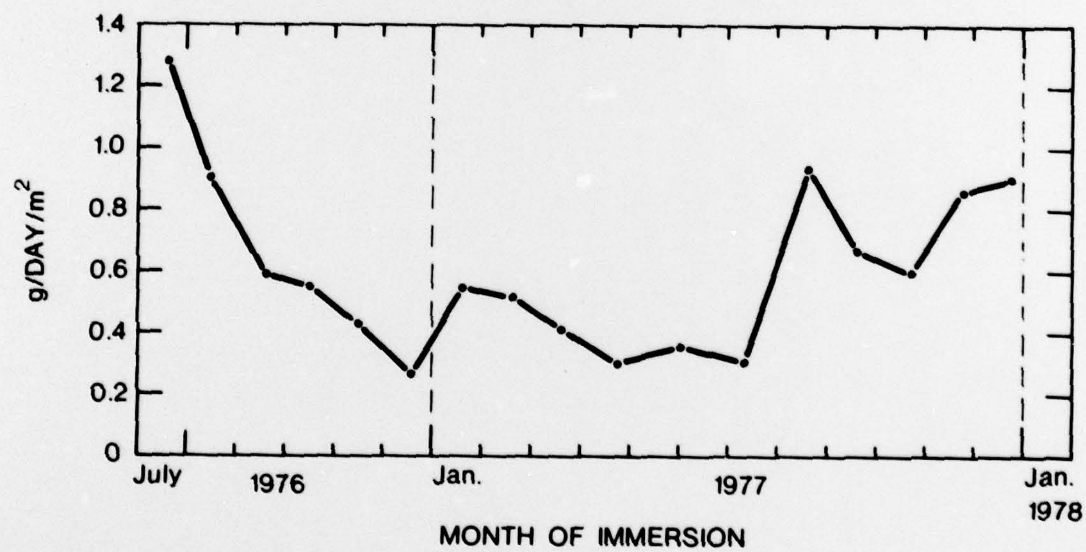

FIG. 8 - Dry weight of fouling accumulated on one-month replacement panels through the study period. Values expressed per day to eliminate influence of varied exposure periods.

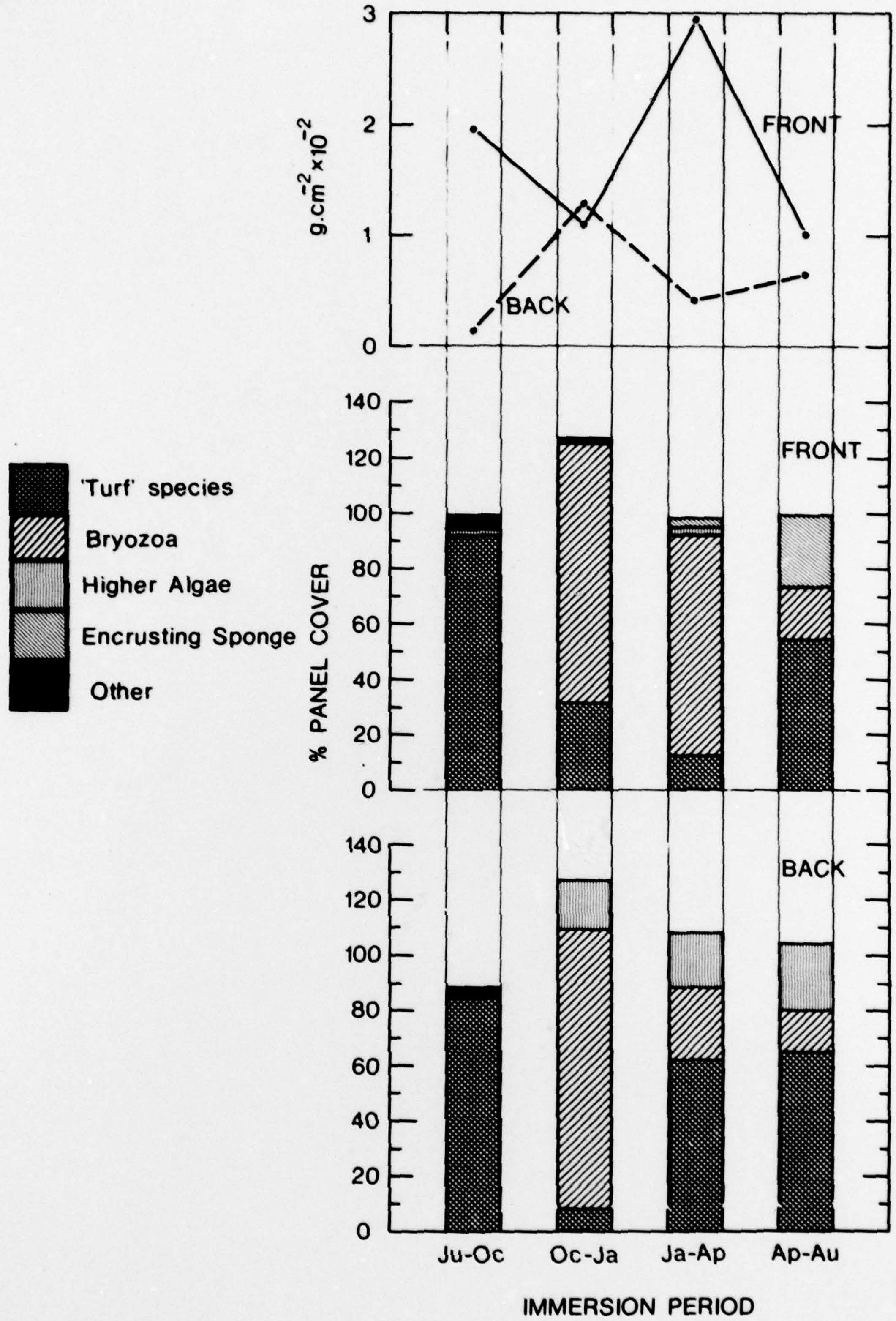

FIG. 9 - Biomass and composition of fouling growth on three-month replacement panels.

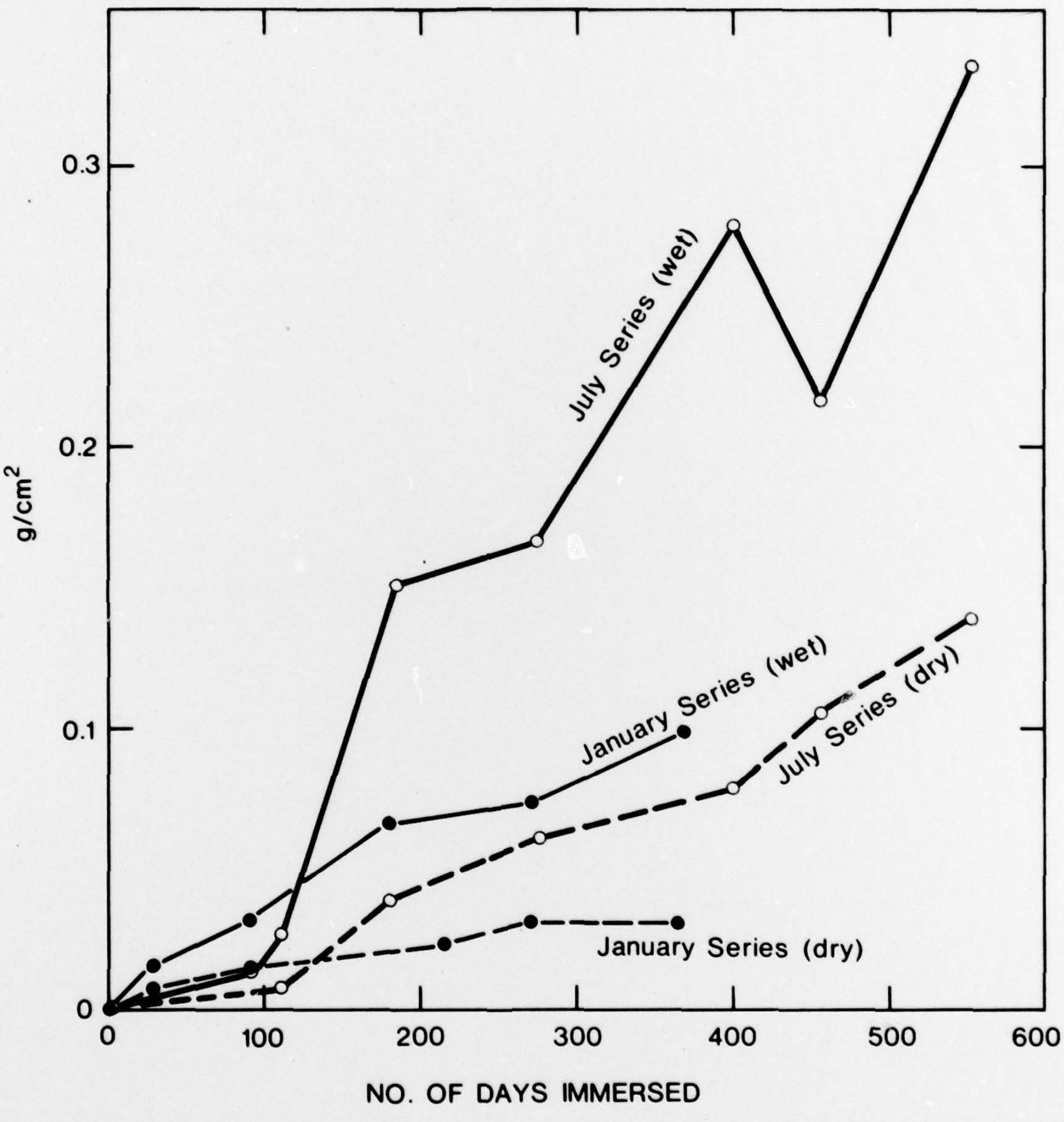

FIG. 10 - Wet and dry weight of fouling growth on July and January successional panel-series.

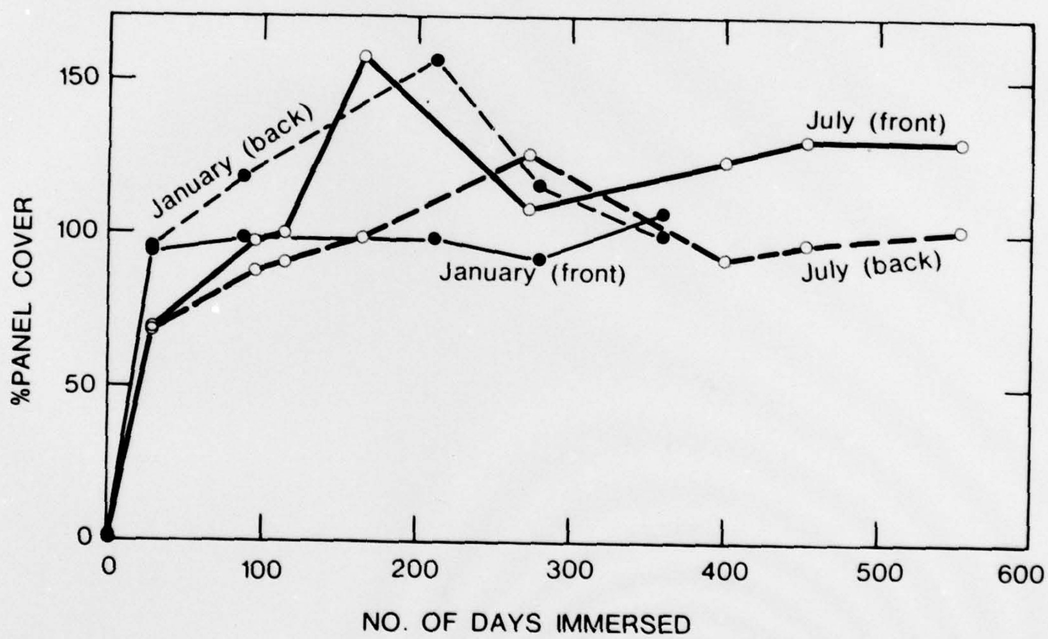

FIG. 11 - Extent of fouling cover on each side of the July and January successional panel-series with increased immersion duration.

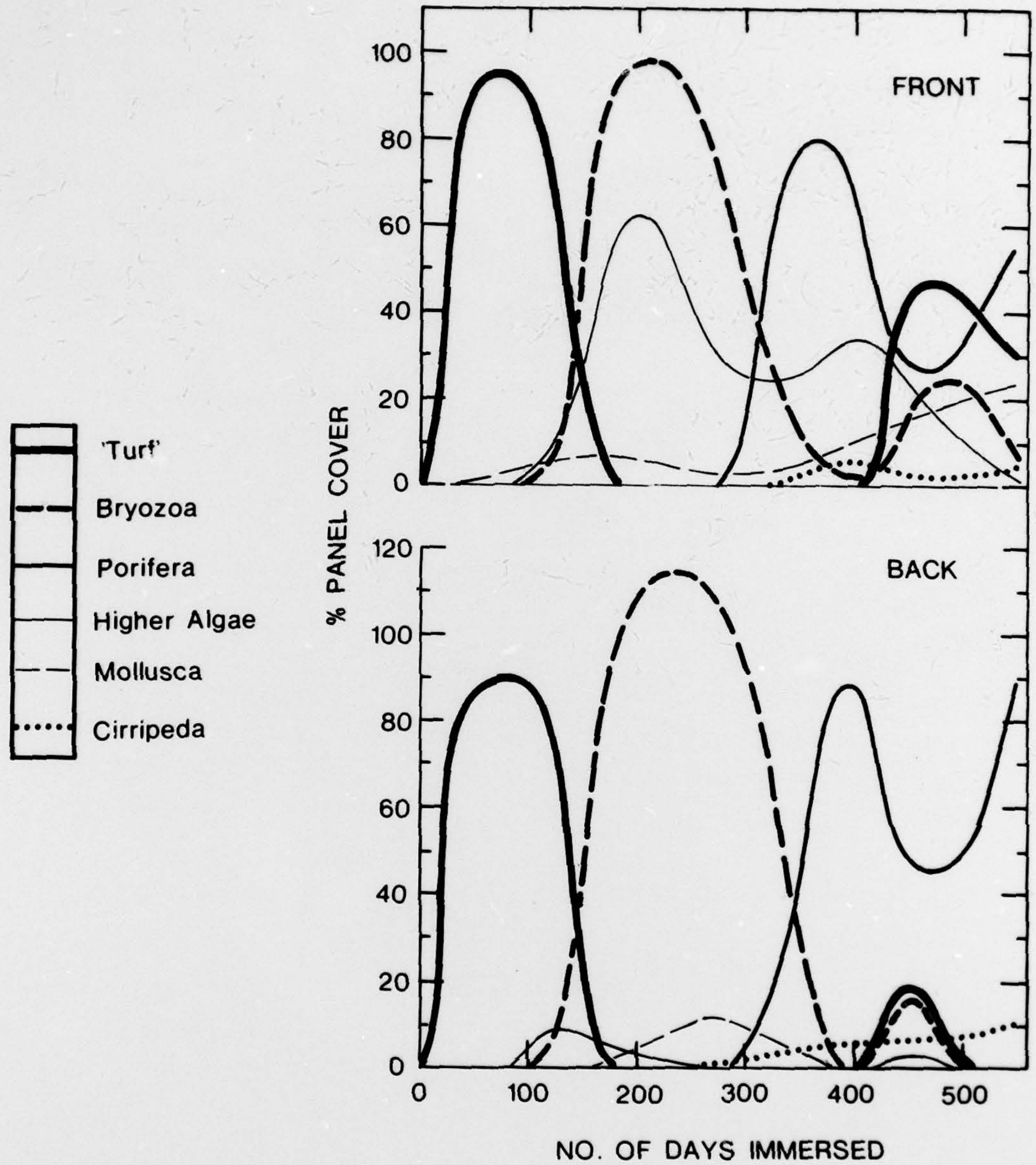

FIG. 12 - Variation in the composition of the fouling community on each face of July successional series with increased immersion time.

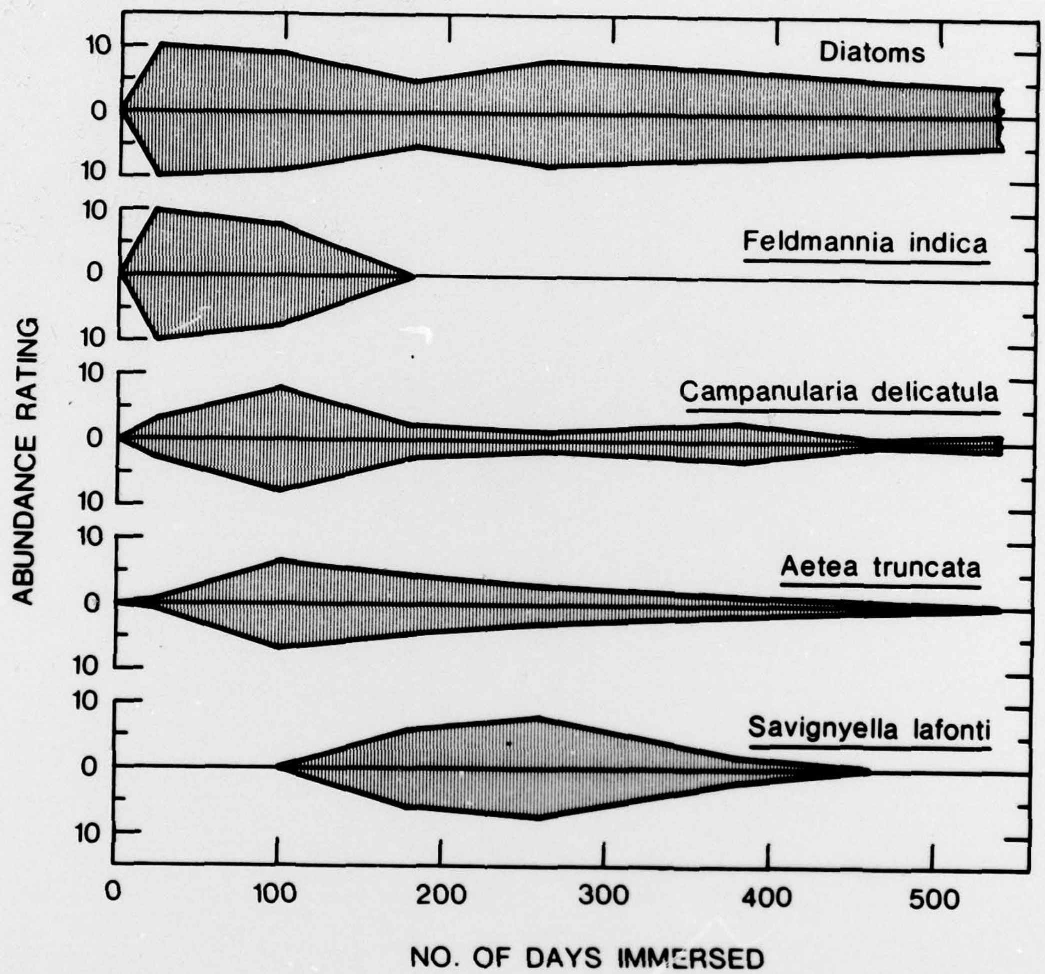

FIG. 13 - Variation in the abundance of turf components with increased immersion time on the July successional series.

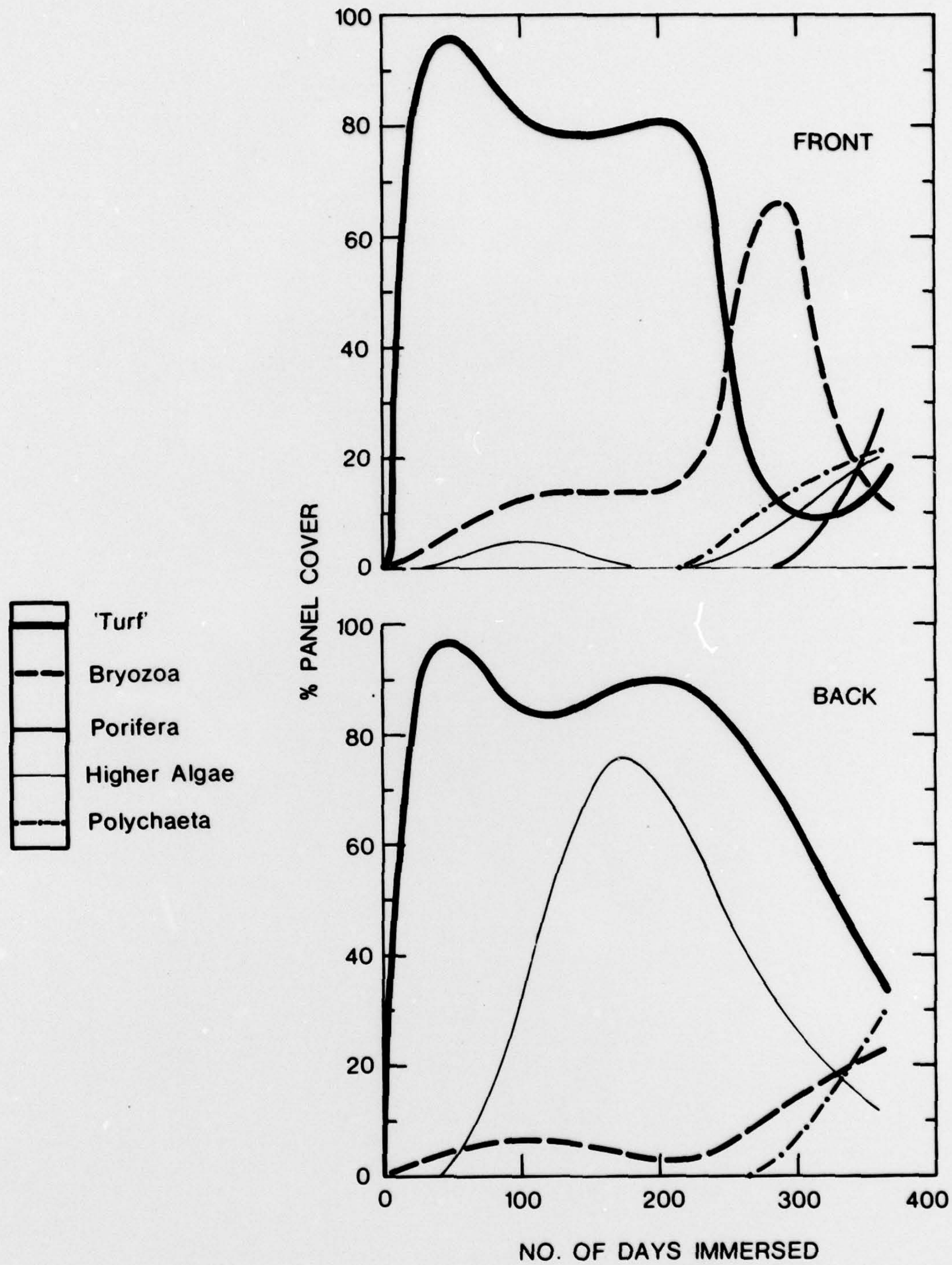

FIG. 14 - Variation in the composition of the fouling community on each face of the January successional series with increased immersion time.

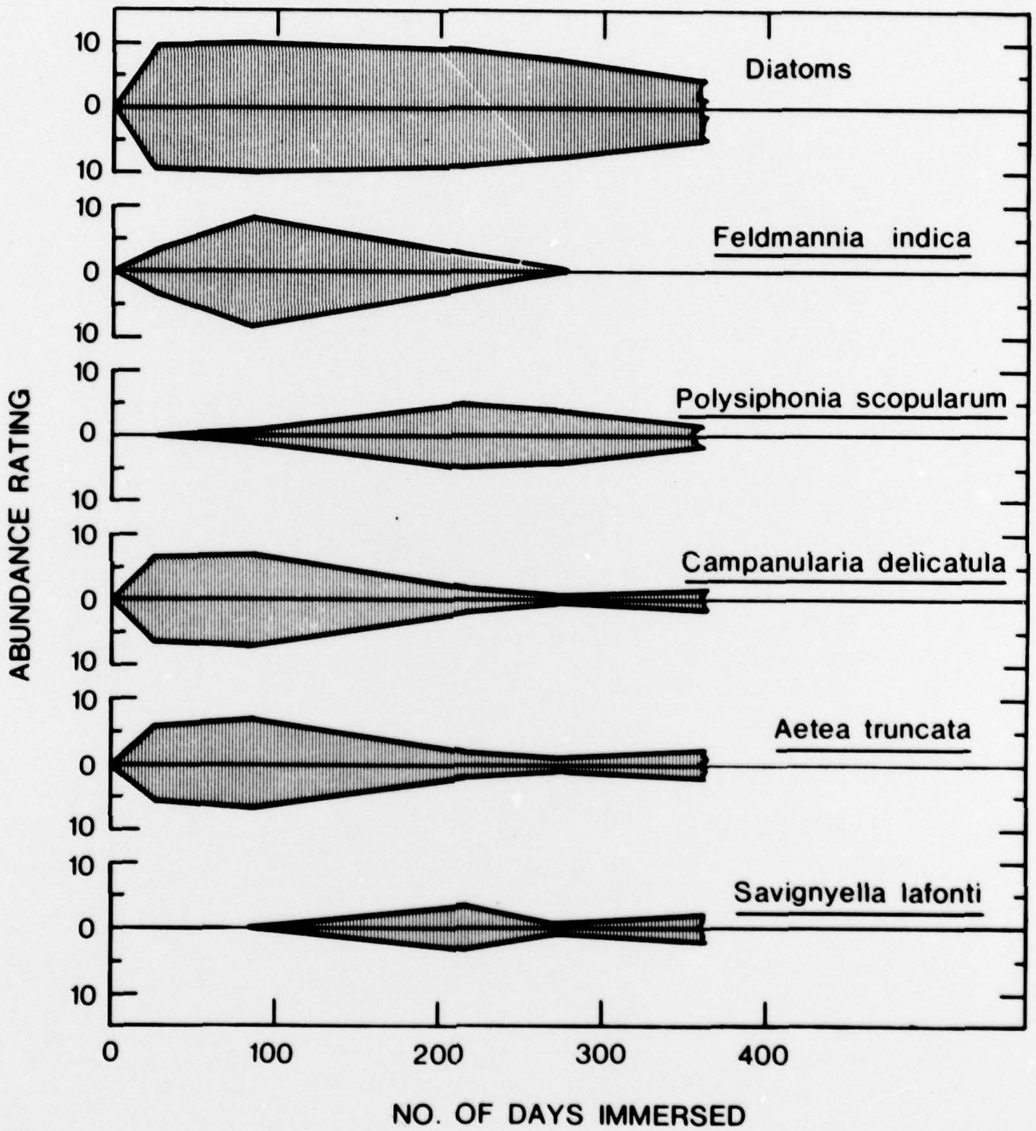

FIG. 15 - Variation in the abundance of turf components with increased immersion time on the January successional series.

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Woods Hole Oceanographic Institution, Woods Hole, Mass. U.S.A.
(Attention: Dr. P.G. Brewer)
Biologische Anstalt Helgoland, Hamburg, West Germany
(Attention: Dr. O. Kinne)
Laboratorio de Ensayo de Materiales e Investigaciones Tecnologicas (LEMIT), Argentina. (Attention: Dr. V. Rascio)
Department of Zoology, National Science Museum, Tokyo, Japan
(Attention: Dr. S. Mawatari)
Marine Science Laboratories, North Wales, U.K.
(Attention: Dr. Crisp)
Scottish Marine Biological Association Laboratory, Scotland
(Attention: Dr. H. Barnes)
Centre ORSTOM, B.P. No.A5, Noumea, New Caledonia
(Attention: Dr. J.R. Donguy)
Fisheries Research Board of Canada, Marine Ecology Laboratory, Bedford Institute, Dartmouth, Canada (Attention: Dr.I. Duedall)
Department of Biological Sciences, Portsmouth Polytechnic, Portsmouth. (Attention: Dr. A. Chamberlain).
Defence Scientific Establishment, HMNZ Naval Dockyard, Auckland
(Attention: Dr. A. Barnes).